NASA Strategy to Safely Live and Work in the Space Radiation Environment

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May 20, 2007

Human in Space Conference, Beijing, China

The Space Radiation Problem

What is it and why should we care?

- What is space radiation?
  - High energy particles, including protons, electrons, and the fully ionized, highly charged nuclei of all the elements; neutrons and other products of interactions with materials
- Exposure to radiation in space is unavoidable.
  - Space radiation penetrates all materials -- spacesuits, spacecraft, habitats, devices, equipment, crew bodies and tissues
- Possible health consequences:
  - Tissue damage, cancer, cataracts, functional brain damage, heart and blood vessel damage, inheritable genetic changes

NASA's Mission: Our Goal

- **The Space Radiation Project must assure that NASA can safely live and work in the space radiation environment, anywhere, any time.**
  - "Safely" means that acceptable risks are not exceeded during crew members' lifetime
  - "Acceptable risks" include limits on mission, post-mission and multi-mission consequences (e.g., excess lifetime fatal cancer risk)
  - The Space Radiation Project strategy must understand the risks and determine methods to mitigate the risks by optimizing the vehicle environment, crew selection criteria and mission length to ensure the consequences of exposure to space radiation are kept as low as reasonably achievable

Where are we now?

- We can’t predict all the significant risks and there is substantial uncertainty in the risks that can be predicted. Insufficient biological knowledge is the largest contributor to the uncertainty
- Prior to 2003, few ground-based accelerators were capable of producing the ions and energies important to NASA
- Risk projection models are based largely on epidemiological data from a population vastly different than the Astronaut population
- Although radiation protection is an important factor in spaceflight, it is not well integrated into the vehicle design process

What are we doing about it ?

- Using a **peer-reviewed research program** to increase our mechanistic knowledge and genetic capabilities to develop tools for individual risk projection, thereby reducing our dependency on epidemiological data and population-based risk assessment
- The **NASA Space Radiation Laboratory** now provides a ground-based facility to study the understanding of health effects/mechanisms of damage from space radiation exposure and the development and validation of biological models of risk, as well as methods for extrapolation to human risk
- Developing a **risk modeling tool** that integrates the results from research efforts into models of human risk to reduce uncertainties in predicting risk of carcinogenesis, central nervous system damage, degenerative tissue disease, and acute radiation effects
- Developing **computer codes to predict radiation transport** properties, evaluate integrated shielding technologies and provide design optimization recommendations for the design of human space systems

Integrated Risk Projection

Mitigation:

- Shielding materials
- Radioprotectants
- Pharmaceuticals

Space Radiation Environment

↓

Radiation Shielding

↓

Initial Cellular and Tissue Damage
DNA breaks, tissue microlesions

↓

DNA repair, Recombination,
Cell cycle checkpoint, Apoptosis, Mutation,
Persistent oxidative damage, & Genomic Instability

↓

Tissue and Immune Responses

↓

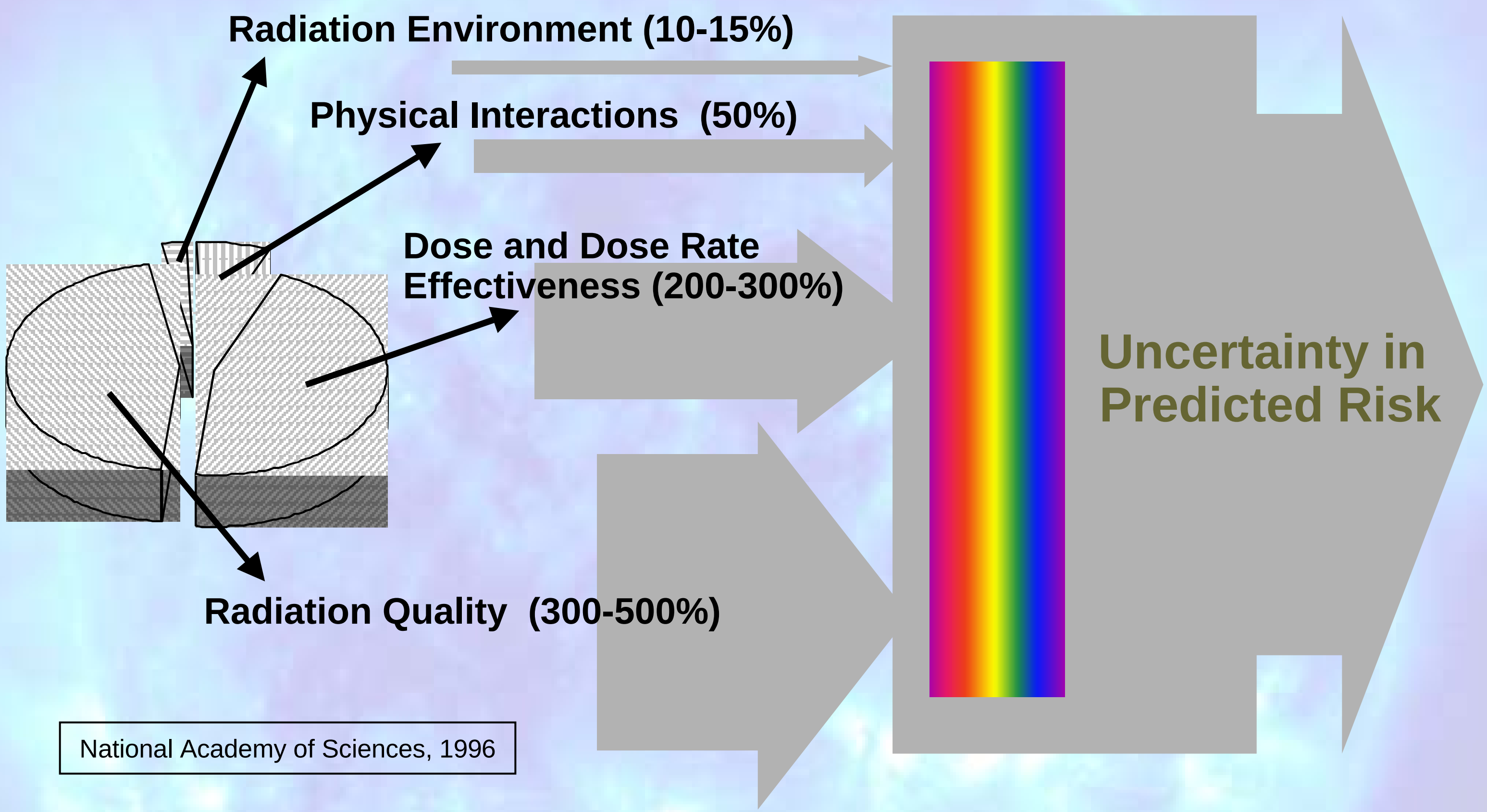
Risks:
Chronic: Cancer, Cataracts, CNS, Heart Disease
Acute: Lethality, Sickness, Performance

Risk Assessment:

-Dosimetry
-Biomarkers
-Uncertainties
-Space Validation

$Risk_j$ (age,sex,mission)

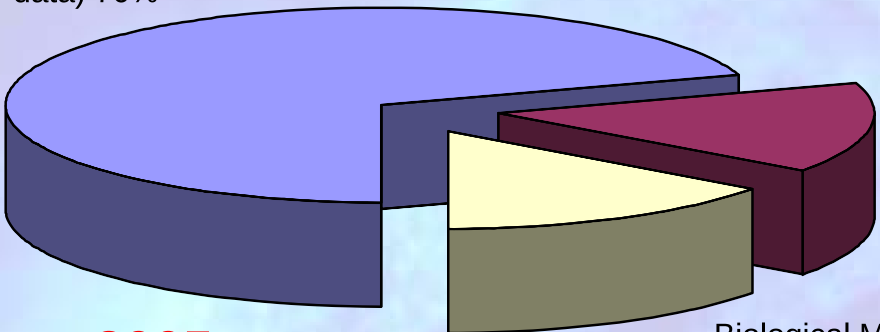
Uncertainty in Predicting Risk



National Academy of Sciences, 1996

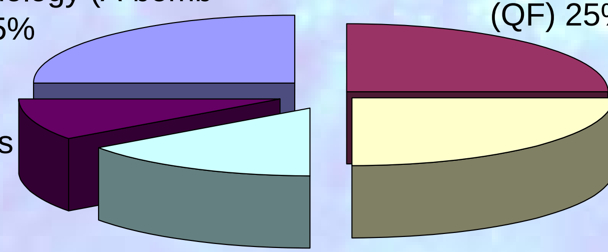
The uncertainties in risk must be reduced to assure radiation safety in space.

Population-Based to Individual-based Risk Projection



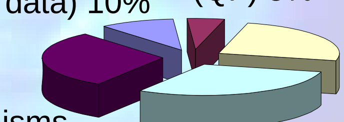
2005
3-5 fold

RISK PREDICTION
Components of Uncertainty



2010
Factor of 2

RISK PREDICTION
Magnitude of Uncertainty

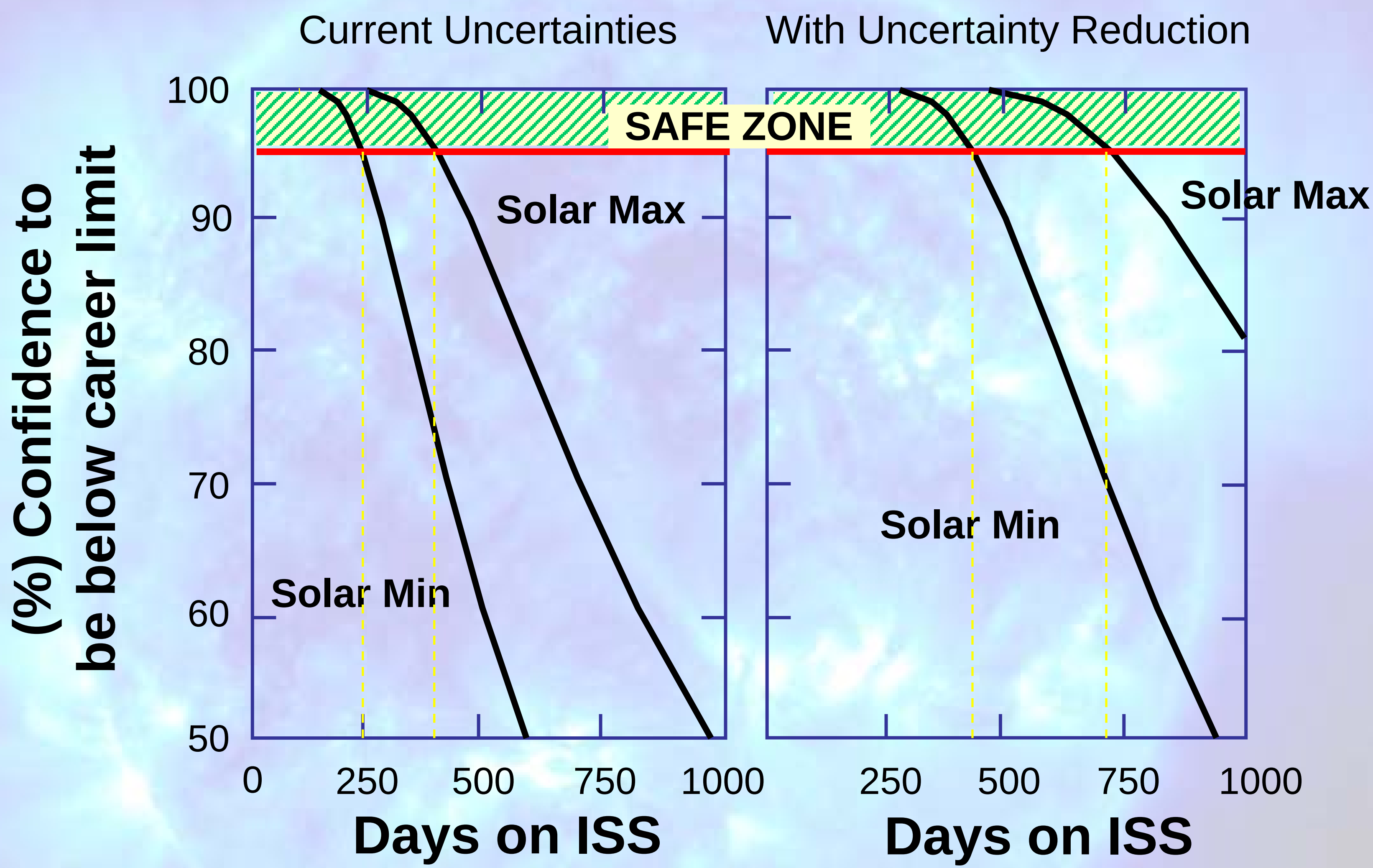


2015
±50%

Reduce size of uncertainty by changing the components (knowledge-based).

Confidence Levels for Career Risks on ISS

EXAMPLE: 45-yr-Old Males; GCR and trapped proton exposures



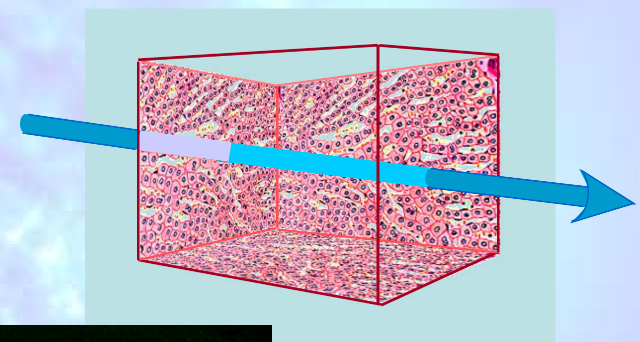
Reducing uncertainty leads to increased "safe" days in space (curves move to the right).

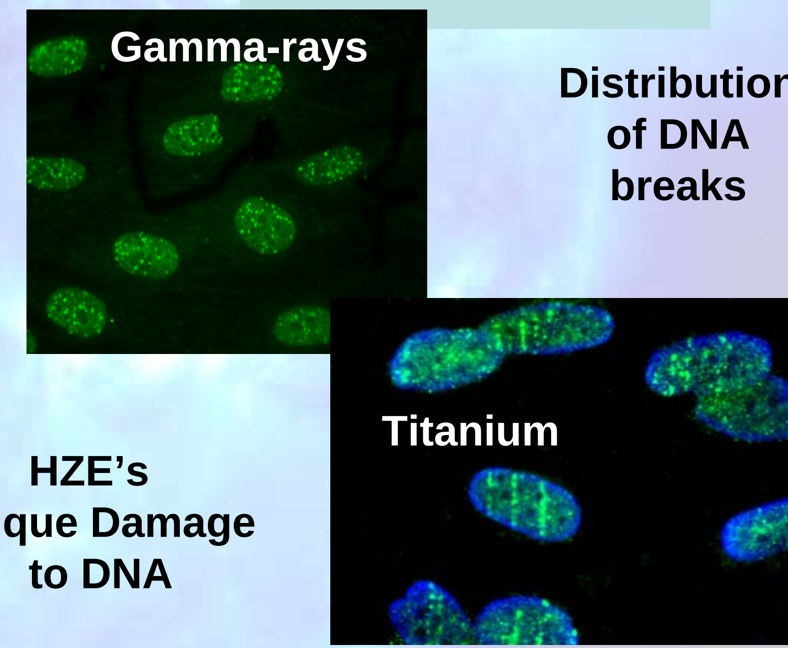
Using a <u>peer-reviewed research program</u> to increase our mechanistic knowledge and genetic capabilities to develop tools for individual risk projection, thereby reducing our dependency on epidemiological data and population-based risk assessment

Peer-Reviewed Research Program to Understand the Space Radiation Problem

- ❑ Unique damage to biomolecules, cells, and tissues occurs from HZE ions
- ❑ Few human data to estimate risk from HZE
- ❑ The mechanisms by which radiation damage to biomolecules and cells develops into health risks are poorly understood
- ❑ Animal models must be applied or developed to estimate cancer, CNS or other risks
- ❑ Effective shielding can reduce, but not eliminate, the space radiation problem.

Tracks Damage Large Numbers of Cells in Integrated Functional Units



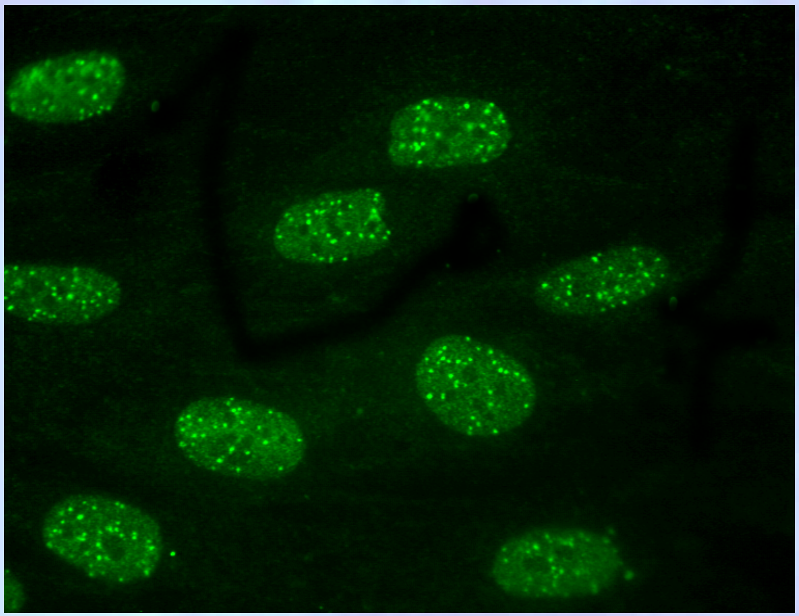


Distribution of DNA breaks

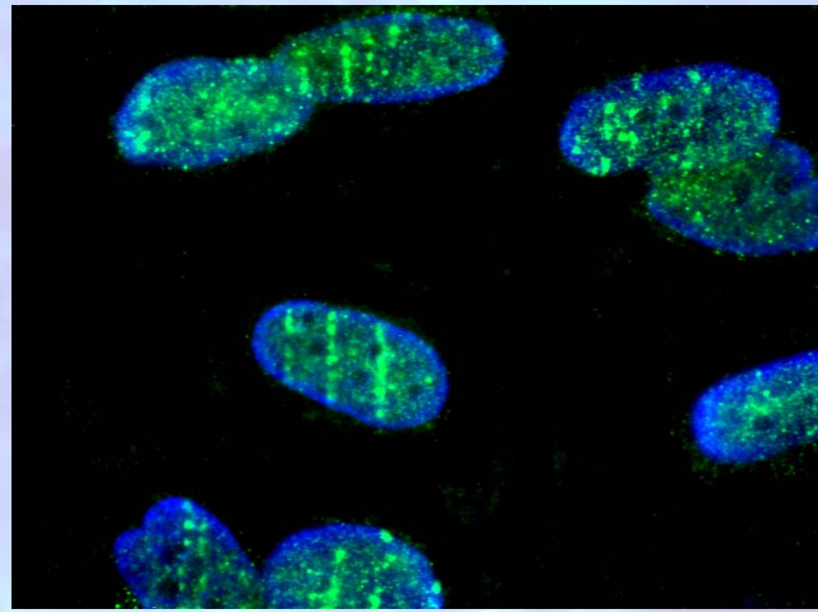
HZE's Unique Damage to DNA

Research on Biological Effects of Heavy Ions

Gamma-rays – 2 Gy



Titanium – 2 Gy



Primary human skin cells irradiated with 2 Gray γ-rays (left) or Titanium ions (right) at NSRL. DNA damage is clearly visible at sites marked by new fluorescent technology. DNA damage is diffuse for γ-rays and localized along the Ti ion tracks through the cells. This pattern of energy deposition accounts for most of the increased risk of space radiation. (Cucinotta et al. 2004)

Ground-based Research Portfolio

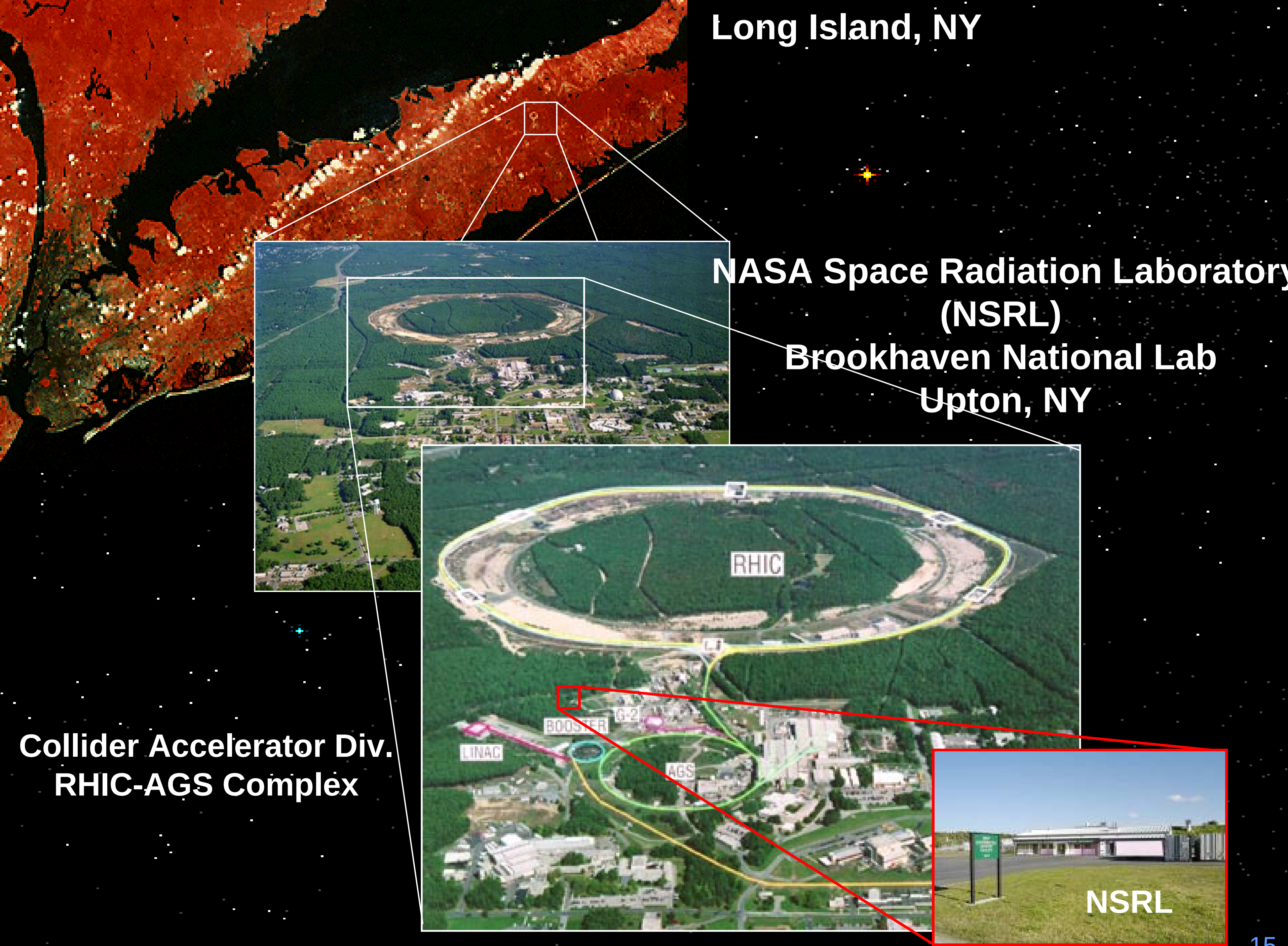
NASA Specialized Center of Research (NSCOR)

- The Space Radiation Project has 5 NSCORs to focus efforts and attract the best researchers and institutions
- NSCORs are solicited for specific critical research areas
  - Leukemogenesis, DNA Damage and Repair, Lung Cancer, Solid Cancer, Progressive Alterations in CNS
- Awards are approximately $2M per year for 5 years
- Results from these “project” like awards provide the scientific basis for improved risk assessment

Individual Research Grants

- The Space Radiation Project has 44 individual research grants, with expectations for selection of 10 new awards per year
- Individual research is solicited in more general research areas
  - Mechanisms of carcinogenesis, CNS effects, Degenerative tissue disease, dietary countermeasures to radiation effects
- Awards are approximately $300K per year for 3 years
- Results from these awards provide the scientific basis for improved risk assessment and help identify additional critical research areas

The **NASA Space Radiation Laboratory** now provides a ground-based facility to study the effects/mechanisms of damage from space radiation exposure



Long Island, NY
NASA Space Radiation Laboratory
(NSRL)
Brookhaven National Lab
Upton, NY
RHIC
G-2
BOOSTER
LINAC
AGS
NSRL
Collider Accelerator Div.
RHIC-AGS Complex

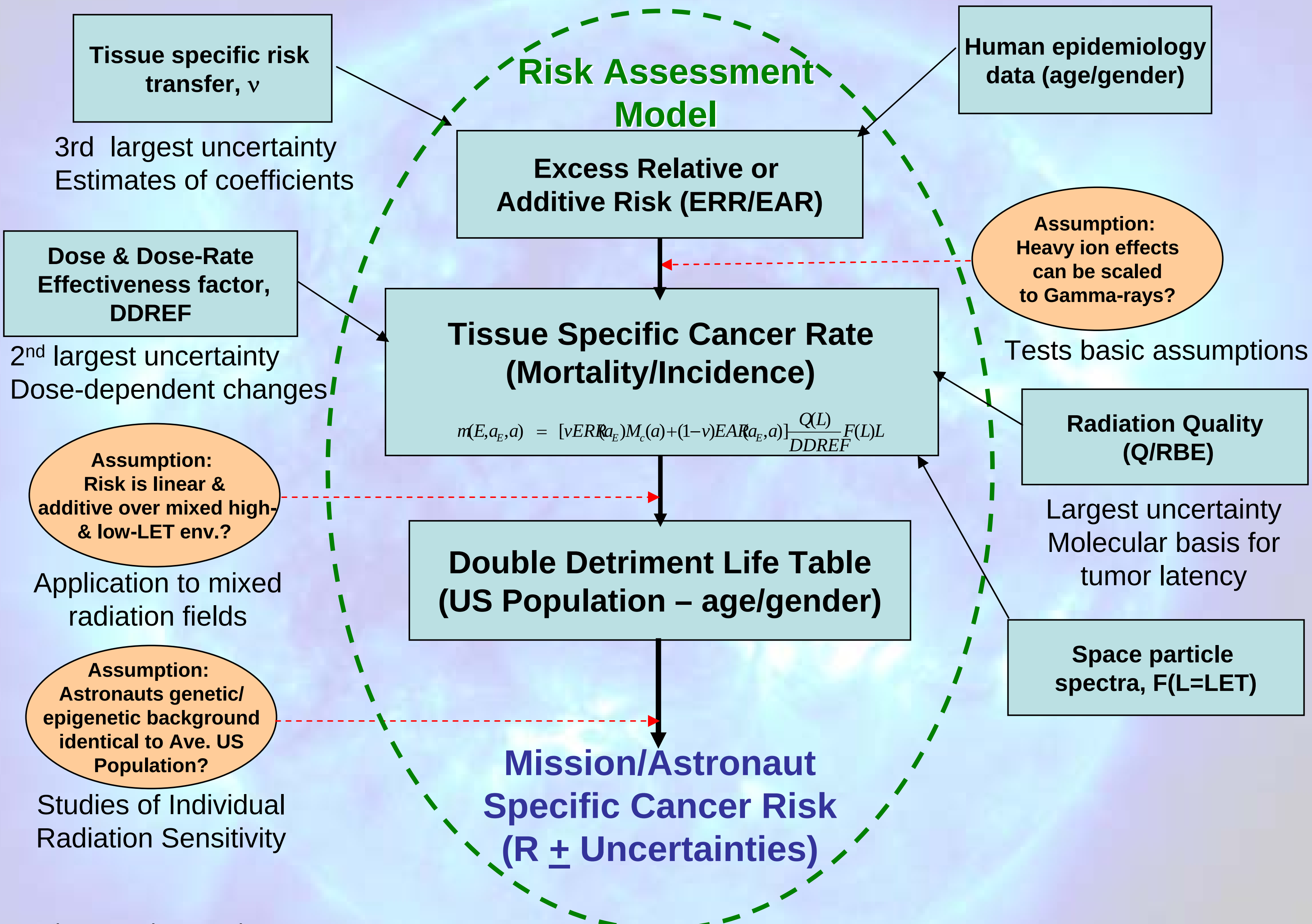
NASA Space Radiation Laboratory

The NASA Space Radiation Laboratory (NSRL), a $34-million facility, is located at DOE's Brookhaven National Laboratory on Long Island and is managed by NASA's Johnson Space Center. The NSRL construction was completed on schedule and within budget. It is one of the few places in the world that can simulate the harsh

cosmic and solar radiation environment found in space. The facility, opened in 2003, employs beams of heavy ions extracted from Brookhaven's Booster accelerator, and has supported 90 investigators from the US and Europe utilizing 2100 hours of beam time (through NSRL-6) to perform experiments with Iron, Titanium, Silicon, Carbon, and protons.

Developing a **risk modeling tool** that integrates the results from research efforts into models of human risk to reduce uncertainties in predicting risk of carcinogenesis, central nervous system damage, degenerative tissue disease, and acute radiation effects

Cancer Risk Assessment Model



Francis A. Cucinotta, Ph.D.

Open Questions for Non-Cancer Risks

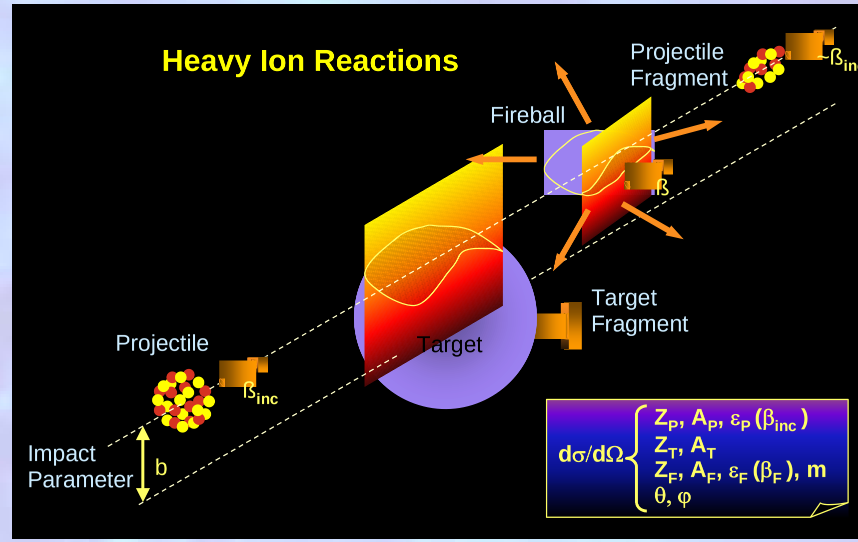
- Risk model cannot be developed without answers to basic questions
- Is there a dose-threshold for non-cancer risks?
- Is multiplicative transfer of cardiac risk the appropriate way to use epidemiology data?
- Will heavy ion CNS risk lead to mission performance impacts?

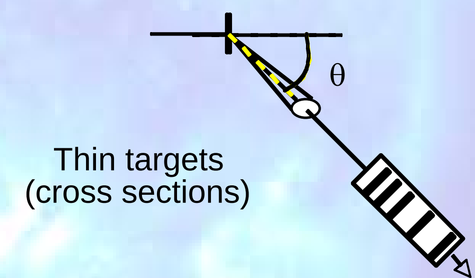
Experimental studies are needed to establish mechanistic basis in support of risk projection

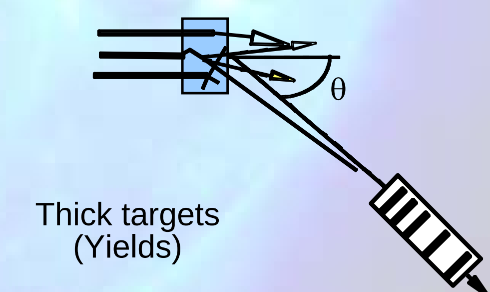
Developing **<u>computer codes to predict radiation transport</u>** properties, evaluate integrated shielding technologies and provide design optimization recommendations for the design of human space systems

Computer Codes to Predict Radiation Transport

- Experimental measurements of physical interactions provide the missing database on nuclear interactions (“cross sections”)
- Experimental measurements also validate the computational tools and radiation shielding materials effectiveness (“yields”)
- Models are used to calculate the changes in radiation as it penetrates and traverses materials (“transport calculations”)

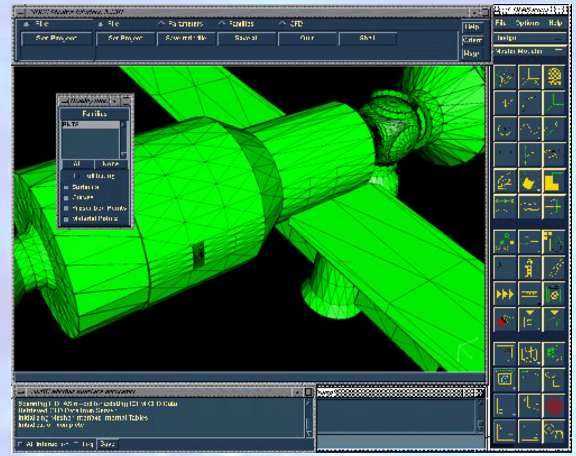


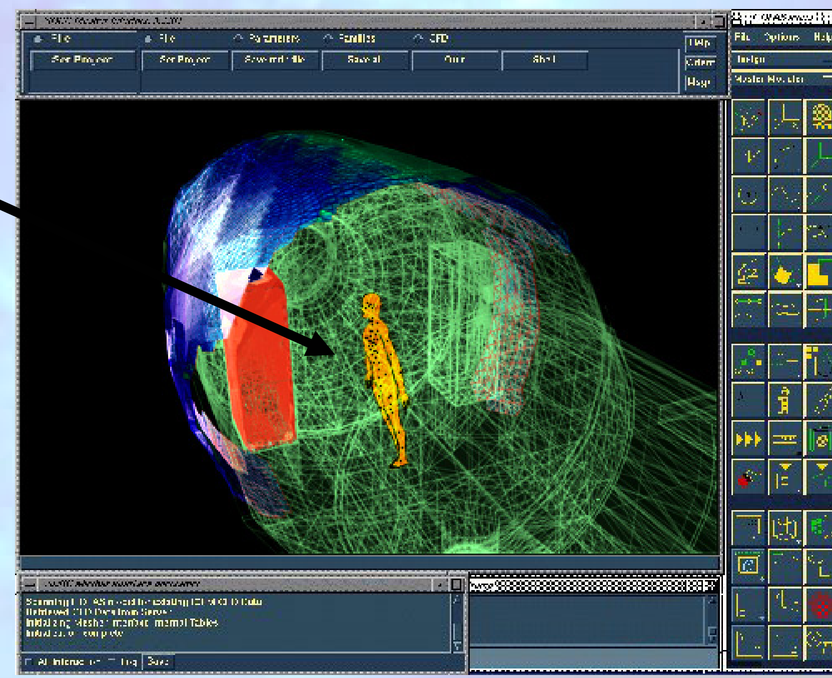




Web-based Design Tool

- User creates CAD model of shielding and defines shield materials consistent with those provided by the Design Tool.
- User has the option of loading the CAD object that incorporates the CAM & CAF target points into their model and placing it in an appropriate location and orientation.
- User executes ray traces using the ray distribution and material definitions downloaded from the Design Tool web site. The target points are either defined by the user or taken from the CAM/CAF target point sets.

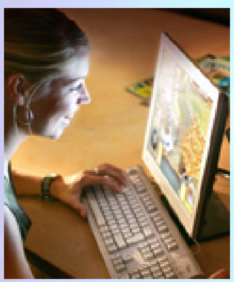


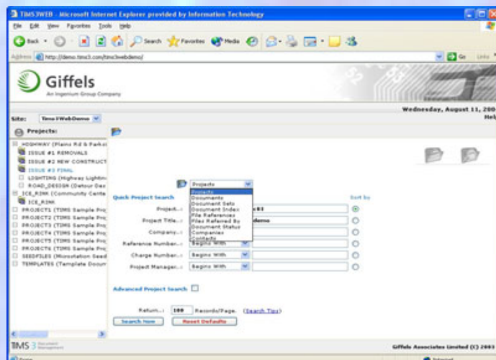


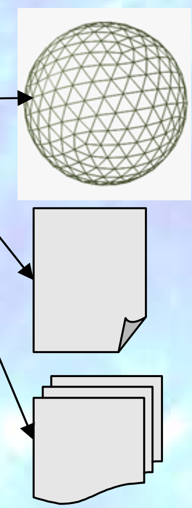
Prototype Use Case for Web-based Design Tool Familiarization & First Use

In this Use Case, the user is responsible for their own CAD modeling and Ray Tracing processes. All other steps of the analysis, including incorporation of the CAM and CAF, are provided by the Design Tool.

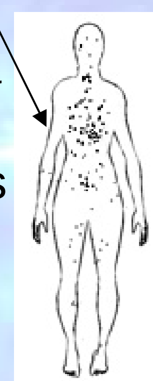
User goes to web site and has access to procedure descriptions, documentation, technical references, and contact lists.







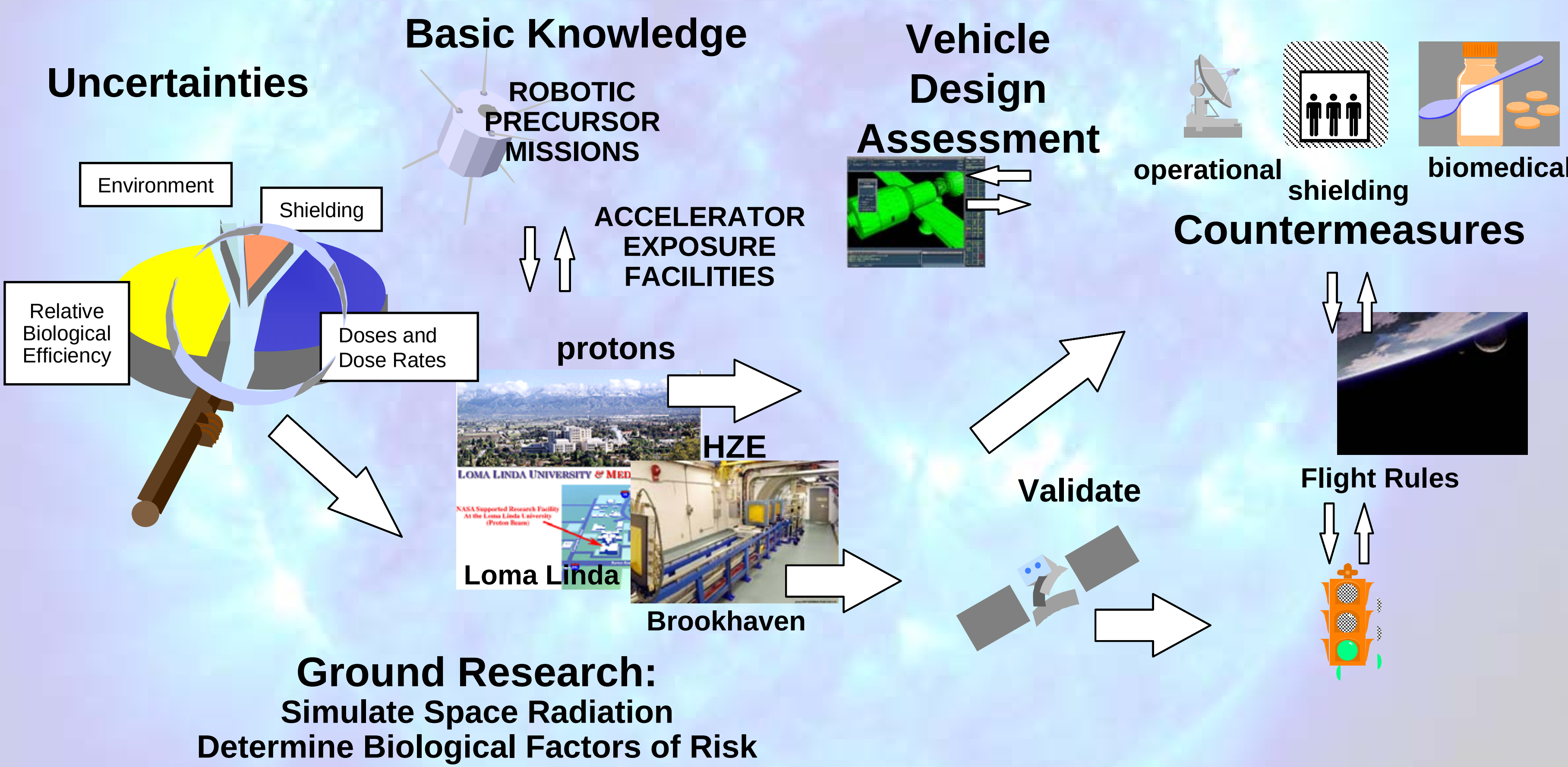
User downloads ray distribution files, file format descriptions, material definitions, example subroutines that can generate the files in the correct format, and scripts that can convert from popular known formats to the Thickness Metafile format required by the Design Tool.



The user can also download a CAD object in either IGES or STEP format that incorporates the CAM & CAF target points with point numbers and labels required by the Design Tool.

CONCLUSION

- Understanding the risks and determining methods to mitigate the risks are keys to a successful radiation protection strategy.




Questions?